A Science-Driven Performance Specification Framework for Space-Based Neutral Hydrogen Cosmology Experiments

Completed Technology Project (2018 - 2020)

Project Introduction

Observations of the highly-redshifted 21 cm hyperfine line of neutral hydrogen (HI) are one of the most promising probes for the future of cosmology. In principle, once the spin temperature of cosmic hydrogen decouples from the Cosmic Microwave Background at z ~ 200, all neutral hydrogen at lower redshifts becomes visible through its hyperfine line emission. Observations at meter wavelength probe the state of HI in the intergalactic medium during the epoch of reionization, offering insight into the nature of the first stars and galaxies — a key component of NASA's Cosmic Origins Program. By pushing observations to higher redshifts (and therefore longer wavelengths), the HI signal becomes the only measurable emission, as luminous objects have yet to form. Observations of these cosmic “dark ages” can offer unprecedented insight into the primordial spectrum of density perturbations and the very nature of inflation, answering questions at the heart of NASA's Physics of the Cosmos Program. At these very low radio frequencies, however, the earth's ionosphere becomes opaque — necessitating observations from space. NASA's “Enduring Quests, Daring Visions” Astrophysics Roadmap recognized the great promise of these observations, and proposed the visionary Cosmic Dawn Mapper — an array of thousands of radio antennas on the far side of the moon — to conduct them. However, the major challenge to neutral hydrogen cosmology (at all redshifts) lies in the presence of bright foreground emission, which can dominate the HI signal by as much as eight orders of magnitude during the dark ages. The only method for extracting the cosmological signal relies on the spectral smoothness of the foregrounds; since each frequency of the HI signal probes a different redshift, the cosmological emission is essentially uncorrelated from frequency to frequency. The key challenge for designing an experiment lies in maintaining the spectral smoothness of the foregrounds. If the frequency response of the instrument introduces spectral structure (or at least, a residual that cannot be calibrated out at the necessary precision), it quickly becomes impossible to distinguish the cosmological signal from the foregrounds. This principle has guided the design of ground-based experiments like the Precision Array for Probing the Epoch of Reionization (PAPER) and the Hydrogen Epoch of Reionization Array (HERA). However, there still exists no unifying framework for turning this design philosophy into a robust, quantitative set of performance metrics and specifications. The goal of this proposal is to develop technology that can directly determine the impact of system design on the science deliverables: measurements of the HI power spectrum and, in turn, constraints on cosmological and astrophysical parameters. This technology will consist of a software suite for end-to-end simulation of the entire instrument and pipeline: encompassing aspects from antenna design, to sources of systematic errors like mutual coupling of elements and cross-talk, through to the analysis tools used. My research group has experience at the forefront of all these aspects of HI cosmology experiments; the work to be proposed here focuses on unifying our most advanced understanding of these issues into one framework. This is far from a trivial task, and requires end-to-end instrument simulations with a level of

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Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Lead Organization:

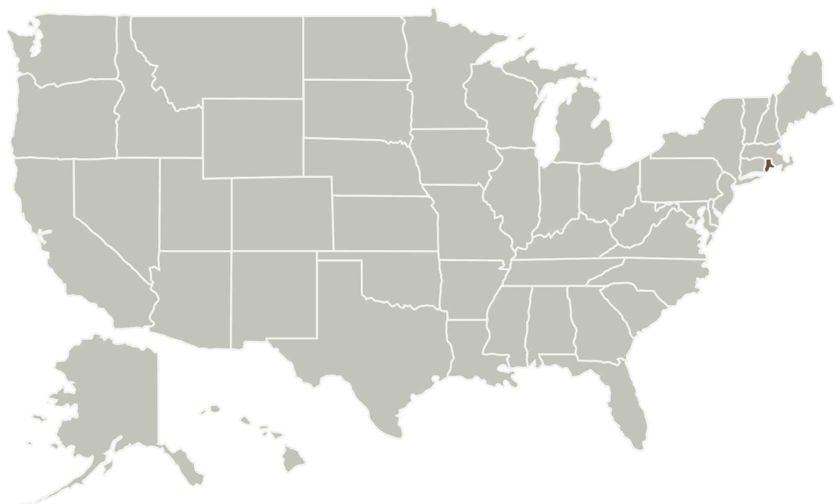
Brown University

Responsible Program:

Astrophysics Research and Analysis

precision never before achieved with low-frequency radio astronomy instrumentation. However, this framework is absolutely necessary for designing any future mission (especially one in space). Science traceability is a fundamental component of mission design, and, at present, HI cosmology experiments cannot connect mission and instrument requirements and specifications directly to the science goals. The work we will propose is therefore mission enabling in the most basic sense: without it, one cannot define the metrics upon which an experiment can be judged.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Brown University	Lead Organization	Academia	Providence, Rhode Island

Primary U.S. Work Locations
Rhode Island

Project Management

Program Director:

Michael A Garcia

Program Manager:

Dominic J Benford

Principal Investigator:

Jonathan Pober

Co-Investigator:

Thomas W Dillon

Technology Areas

Primary:

- TX08 Sensors and Instruments
  - └ TX08.1 Remote Sensing Instruments/Sensors
    - └ TX08.1.4 Microwave, Millimeter-, and Submillimeter-Waves

Target Destination

Outside the Solar System